NASA/GSFC Contract NASW-01122

Next Generation Transport Phenomenology Model

Final Report, 22 September 2004

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ABSTRACT

This report summarizes the results of work done for the Next Generation Transport Phenomenology Model contract. In this project, previously developed and validated electron and photon transport models for the upper atmosphere and related optical emissions codes were reengineered and incorporated into Aeronomy Phenomenology Modeling Tool (APMT), an open source software system for modeling, analysis, and simulation. Distributed and coarse grain parallel computing capabilities were provided by CPI's Enterprise Java CORBA Component Model (EJCCM), a middleware framework based on the CORBA Component Model (CCM). There have been a number of useful benefits to this reengineering effort. Specifications have been written for each of the transport solutions, providing descriptions of the solution techniques at a level of detail not previously available. The reengineered transport solution codes offer improved maintainability, more extensive code reuse where similar algorithms are used in different models, and greater flexibility for studying general planetary atmospheres. Also, a new website (www.cpi.com/apmt) has been developed with graphical user interfaces (GUIs) for running and accessing output from the APMT photoelectron and auroral electron models over the Internet.

INTRODUCTION

The legacy Fortran versions of the electron and photon transport models discussed here have been used to obtain derived data products from remote sensing data, particularly far UV data. The derived data products include information on atmospheric composition, solar EUV flux, and auroral energy inputs to the atmosphere. Examples of remote sensing applications using these models are Strickland et al. [2000; 2001a,b; 2004a,b] and Hecht et al. [2000]. Experiments addressed are DE-1/FUV imaging, TIMED/GUVI, and those making auroral observations from rockets and from the ground.

The main legacy Fortran codes involved here are

- AURIC – dayglow and nightglow model (Strickland et al. [1999])
- B3C – auroral electron, proton, and hydrogen atom transport model (Strickland et al. [1993])
- Redister – resonance line photon transport model (Gladstone, [1988])

When these models are used, input and output is passed between programs as flat files. A series of runs is configured and executed through Interactive Data Language procedures, Unix shell scripts, or DOS BAT files. The main purpose of this project was to replace this flat file / operating system-based approach with a middleware-based approach, which would allow concurrent and distributed processing and easier integration of models into software applications. The middleware framework applied to this task was CPI's Enterprise Java CORBA Component Model (EJCCM, www.ejccm.org), a Java implementation of Object Management Group's CORBA Component Model (CCM).

With the new system, Aeronomy Phenomenology Modeling Tool (APMT), model functionality is implemented in EJCCM components. The Fortran programs of AURIC, B3C, and Redister were either reengineered in Java or directly embedded through wrappers. The first significant application of the new system has been the development of a website, www.cpi.com/apmt, with interfaces to APMT's photoelectron and auroral electron models. In the future we expect to apply the APMT system in the analysis of TIMED/GUVI data and mission support for the Space Environmental Sensor Suite of the National Polar-orbiting Operational Environmental Satellite System (NPOESS). To the best of our knowledge, CPI's APMT system represents the first web-based aeronomy modeling tool that is freely available and accessible to the general public, and we expect APMT to be fully exercised in important aeronomy applications by various research groups throughout the space science community.

ACCOMPLISHMENTS

Specifications

Specifications were written, providing descriptions of the solution techniques at a level of detail not previously available. These were included with earlier quarterly reports and can also be accessed at www.cpi.com/tpmtspecifications/:

- Altitude Grids for Auroral Electron Transport
- Calculate Electron Transport Solution
- Calculate Matrix Elements
- Calculate Resonance Line Photon Transport Solution
- Energy Grids for Auroral Electron Transport
- Extend Auroral Electron Transport Solution to Low Energies Using Local Approximation
- Photoelectron Source Function
- Testing the Auroral Electron Solution
- Testing the Local Photoelectron Solution for Energy Conservation

Reengineering

A number of models, which were previously implemented in Fortran, were implemented in Java, with an emphasis on improved code reuse over the earlier versions and greater

flexibility for application to general planetary atmospheres. The reengineered models include:

- Local solution for photoelectrons (from AURIC)
- Auroral electron transport solution (from B3C)
- Resonance line photon transport (from Redister)
- Post-processing code for optical emission features, including volume and column emission rates

See Appendix C for some examples of plots of model output.

The new Java code has been unit tested and found to produce results consistent with the earlier Fortran codes. This testing was described in earlier quarterly reports. Some integration testing remains to be done for the system as a whole.

Wrappers

Some Fortran programs have been incorporated directly into APMT through the use of wrappers. These include:

- MSIS90 for neutral densities and temperatures
- Model ionosphere program
- Synthetic spectra for molecular band systems

Website

The APMT web interface, www.cpi.com/apmt, was implemented as a Tomcat servlet (see jakarta.apache.org/tomcat). The servlet communicates with the APMT server via CORBA method calls on APMT components. The interface includes capabilities for

- Configuring and executing photoelectron and auroral electron model runs
- Downloading model results in netCDF format (my.unidata.ucar.edu/content/software/netcdf)
- Viewing plots of model output

Screen captures and documentation from the website are included in the appendix of this report. In particular, see Appendix A for a more complete discussion of the capabilities of the website.

Things left to be done

One of our main goals has been to ensure that much of the same modeling capabilities of AURIC and B3C were included in APMT so that APMT would be a viable alternative to the earlier models. This goal has been met with regard to the most challenging aspects of the modeling, namely the generation of photoelectron and auroral electron fluxes. In turn, the capability is in place for generating excitation and column emission rates by

electron impact for many spectral features. There are additional capabilities that will be added to APMT either shortly or through subsequent projects. These capabilities within the following programs will be embedded through wrappers:

- Daychem - a model for calculating equilibrium chemical densities and volume emission rates from radiative decay of metastable species for the photoelectron model.
- Lyman α and β apparent column emission rates for the dayglow model
- Auroral chemistry code
- Proton and hydrogen atom transport for the auroral model

Other capabilities to be added:

- Photoelectron transport (as opposed to the local solution for photoelectrons)
- Nightglow

Also, we will post the APMT source code, which is meant to be open source, on the website (www.cpi.com/apmt) once testing is complete for the whole system.

REFERENCES

Gladstone, G. R., UV resonance line dayglow emissions on Earth and Jupiter, *J. Geophys. Res.*, *93*, 14,623, 1988.

Hecht, J. H., D. L. McKenzie, A. B. Christensen, D. J. Strickland, J. P. Thayer, and J. Watermann, Simultaneous observations of lower thermospheric composition change during moderate auroral activity from Kangerlussuaq and Narsarsuaq, Greenland, *J. Geophys. Res.*, *105*, 27,109, 2000.

Strickland, D. J., J. L. Lean, R. R. Meier, A. B. Christensen, L. J. Paxton, D. Morrison, J. D. Craven, R. L. Walterscheid, D. L. Judge, and D. McMullin, Solar EUV irradiance variability derived from the terrestrial dayglow, *Geophys. Res. Lett.*, *31*, L03801, doi:10.1029/2003GL018415, 2004b.

Strickland, D. J., R. R. Meier, R. L. Walterscheid, A. B. Christensen, L. J. Paxton, D. Morrison, J. D. Craven, and G. Crowley, Quiet-time seasonal behavior of the thermosphere seen in the far ultraviolet dayglow, *J. Geophys. Res.*, *109*, A01302, doi:10.1029/2003JA010220, 2004a.

Strickland, D. J., J. D. Craven, and R. E. Daniell, Six days of thermospheric/ionospheric weather over the Northern Hemisphere in late September 1981, *J. Geophys. Res.*, *106*, 30,291, 2001b.

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Strickland, D. J., J. H. Hecht, A. B. Christensen, and D. J. McEwen, Thermospheric disturbance recorded by photometers on-board the ARIA II rocket, *J. Geophys. Res.*, *105*, 2461, 2000.

Strickland, D. J., J. E. Bishop, J. S. Evans, T. Majeed, P. M. Shen, R. J. Cox, R. Link, and R. E. Huffman, Atmospheric ultraviolet radiance integrated code (AURIC):

theory, software architecture, inputs, and selected results, *J. Quant. Spect. Rad. Transfer*, *62*, 689, 1999.

Strickland, D. J., R. E. Daniell, Jr., B. Basu, and J. R. Jasperse, Transport-Theoretic Model for the Electron-Proton-Hydrogen Atom Aurora: 2. Model Results, *J. Geophys. Res.*, *98*, 21533, 1993.

APPENDIX A:
How to use the APMT models

(from APMT Web Interface, www.cpi.com/apmt/model_how_to.htm)

Contents

1. Introduction

APMT stands for Aeronomy Phenomenology Modeling Tool. APMT includes a photoelectron model and an auroral electron model, which can be used to calculate energetic electron fluxes and related optical emission rates. APMT is intended to eventually include all of the same modeling functionality as CPI's previously developed models, AURIC and B3C.

The development of this website and the APMT models was funded by NASA's Applied Information Systems Research Program (AISRP).

On the main page, three links are given for interacting with each of two models: "Set parameters and execute model," "Browse results," and "Browse incomplete/pending runs." These are discussed in the following sections.

2. Set parameters and execute model

Links are provided to the "Set parameters..." page for each of the two models (photoelectron and aurora) on the main page. When accessed this way the page starts out with default parameters. Links are also provided to this page for previous runs so you can modify and reuse parameters from previous runs (see sections 3 and 4 below).

Parameters

The parameters are grouped under the following headings:

For both models:

- Run name - identifies run, cannot be a duplicate of a previously used run name
- Geophysical parameters - These are inputs to the MSIS90 model for calculating neutral densities and temperatures. For the photoelectron model they are also

inputs for the FAIM ionospheric model and a model for scaling the Hinteregger reference solar EUV spectrum. See www.cpi.com/apmt/things_not_done_yet.htm for a discussion of work left to be done on how these parameters are set.

- Viewing geometry - you can specify lists of observer altitudes and zenith look angles here. Optical emission feature column emission rates and synthetic spectra for molecular band systems will be computed for each observer altitude - zenith look angle combination. There is currently a maximum of 50 observer altitude - zenith look angle combinations per run. The total spectra plots will not be generated if the number of combinations exceeds 15. Note that the run will not be allowed to start unless the highest observer altitude is below the highest altitude grid point.
- Spectral parameters - these are inputs to the synthetic spectra models for molecular band systems (e.g. N_2 LBH).
- Molecular band system synthetic spectra options - a checkbox is provided for each molecular band system for which a synthetic spectrum can be computed. Deselecting a particular synthetic spectrum will speed up the run.
- Resonance line photon transport options - a checkbox is provided for each optically thick emission feature. This determines whether the resonance line photon transport solution will be computed for each feature. Again, deselecting a particular feature will speed up the run.

Photoelectron model only:

- Adjustments to Hinteregger spectrum - This allows a scale factor to be applied to the solar EUV spectrum over a range of wavelengths.

Auroral electron model only:

- Incident flux - parameters describing the incident electron flux
- Ionosphere (exponential) - parameters describing electron densities varying exponentially with altitude. The density is used to provide an approximate description of energy loss to plasma with primary interest at F-region heights.

Running the models

Click the "Compute" button. There are two basic options:

- If the "Wait for run to complete" checkbox is checked then a new page will not load until the run is complete. When the run is complete a "Browse Results" page will be displayed (see below) for the run just completed.
- If the checkbox is not checked then you can go ahead and configure and start another run after clicking Compute. You do not have to wait for a run to finish before starting another run. This means you can start a series of runs and then come back later to see the results. Note, however, that the website will not accept any new runs if there are more than 20 runs currently pending.

3. Browse results

This page provides access to output from completed runs for a particular model (photoelectron or auroral). If this page is accessed from the main page, then all completed runs for the model are displayed. This page will also be loaded after a run has been completed if the "Wait for run to complete" checkbox is checked in the "Set parameters and execute model" page (see above). In this case only the output for a particular run will be listed. For each completed run listed, the following types of links are provided, which are discussed below:

- NetCDF output
- Postscript plots
- View parameters
- Modify and reuse

NetCDF output

Numerical output from the model is provided in the netCDF format. The netCDF files can be downloaded from the Browse Results pages. The output includes

- Neutral densities and temperatures
- Electron densities
- Solar flux (for photoelectron model)
- Incident electron flux (for auroral electron model)
- Volume emission rates
- Column emission rates and synthetic spectra (indexed by observer altitudes and look angles)
- Spherical electron fluxes

Reading data in netCDF format:

- The file at the following link includes an Interactive Data Language (IDL) procedure for reading the APMT output netCDF files as well as instructions on how to use the procedure and some plotting examples www.cpi.com/apmt/idl_netCDF.pro.txt.
- Software libraries for reading and writing data in the netCDF format are available for a number of different programming languages at my.unidata.ucar.edu/content/software/netcdf/index.html.

Postscript plots

A postscript file with plots of model output is automatically generated for each model run. The file includes the following plots:

- Volume emission rates for certain optically thin emission features (including N_2 LBH) and all user-selected optically thick emission features

- Column emission rates for all user selected optically thick emission features. Usually these are plotted versus zenith look angle, but if there is only one zenith look angle and there is more than one observer altitude, then the column emission rates will be plotted versus observer altitude (i.e. rocket mode).
- Total spectra for each look angle - observer altitude combination. This includes molecular band systems and all other emission features computed by the model. If the number of look angle - observer altitude combinations is greater than 15 then these plots are omitted.
- Neutral densities and temperature
- Electron densities

A viewer for postscript files can be obtained at www.cs.wisc.edu/~ghost/gsview/index.htm. It should be possible to open the plot files directly from the Browse Results web page if the ".ps" extension is associated with the gsview executable.

View parameters

This displays all of the parameter settings for a particular model run. The parameter values are displayed only as text, and not in forms, so you can easily cut and paste the parameter values from this page into another document or print the parameter values. Other than this, there is not that much use for this page, since the "reuse parameters" selection (see below) also displays parameters.

Reuse parameters

This loads the "Set parameters and execute model" page with the parameter values used for a previous run so you can modify the parameters and start a new run.

4. Browse incomplete/pending runs

This page provides information (for a particular model) on which runs have not yet been completed and which runs have ended due to errors. For each run it provides links for viewing and reusing the parameters as in the "Browse results" page. If a run ends due to an error then this should be reported to the email address listed below for APMT.

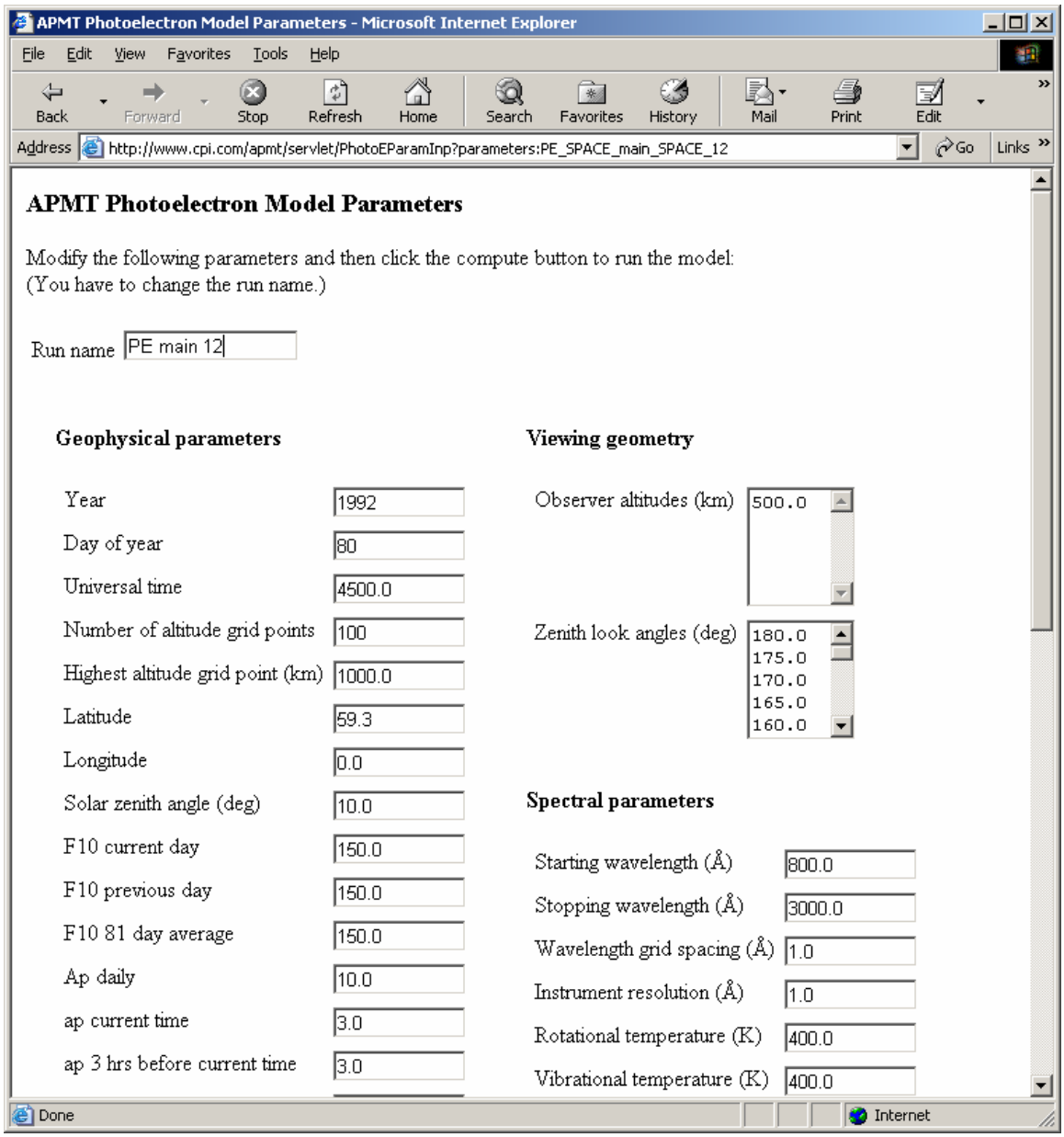
5. Contact information

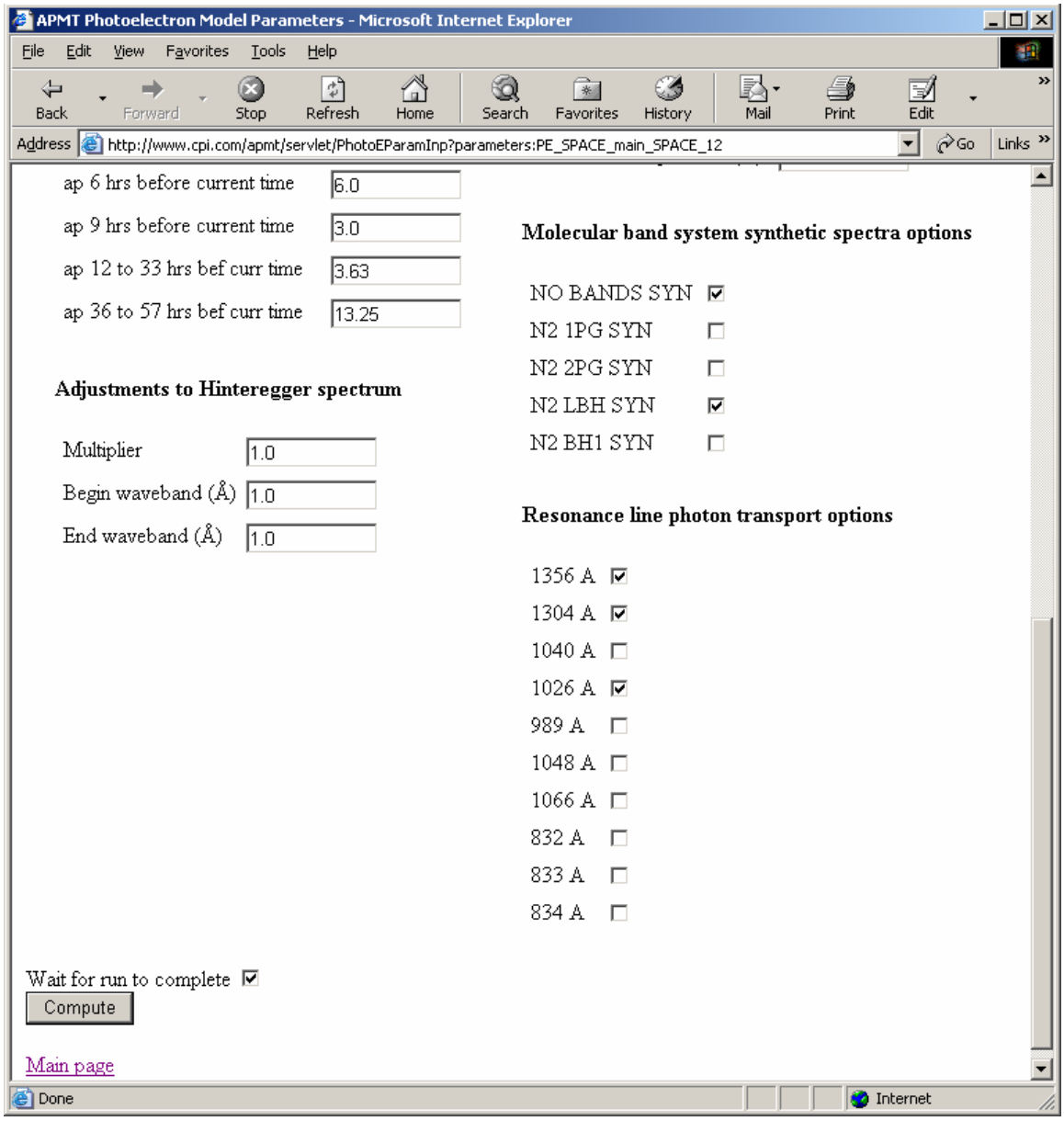
apmt@cpi.com

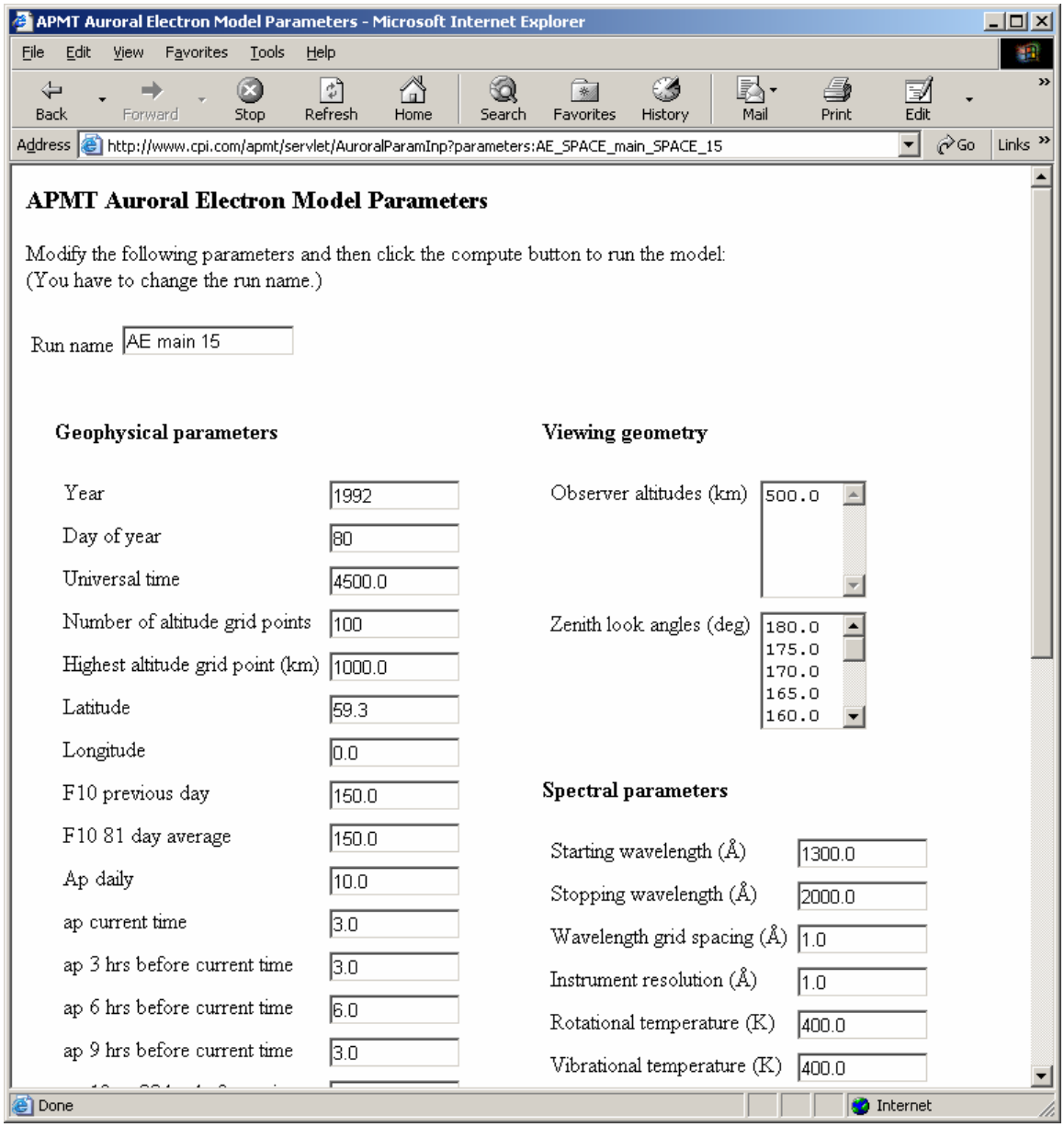
Main page

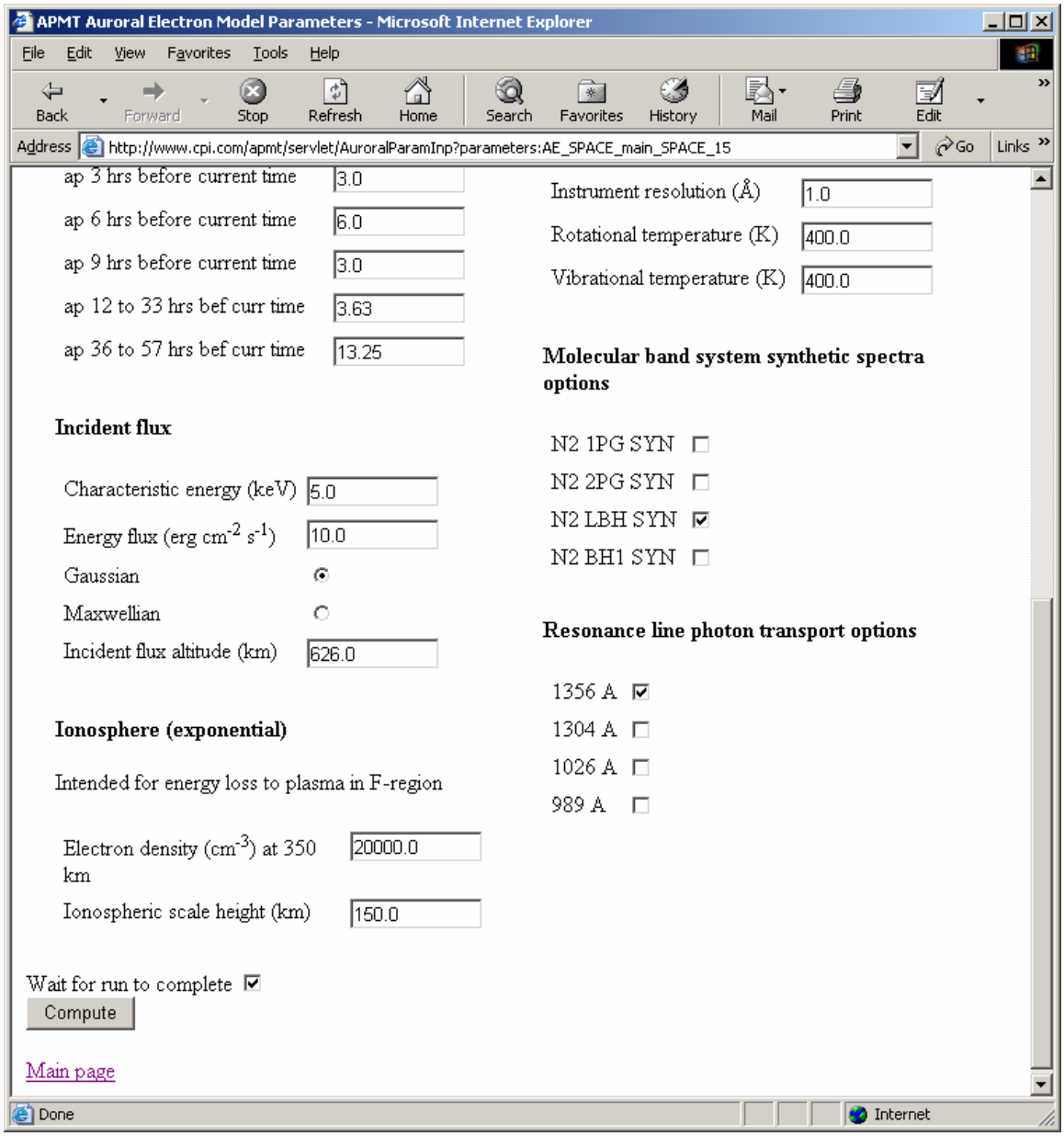
APPENDIX B:
Screen Captures from the Website

The following four screen captures show the website forms for configuring and executing photoelectron and auroral model runs.

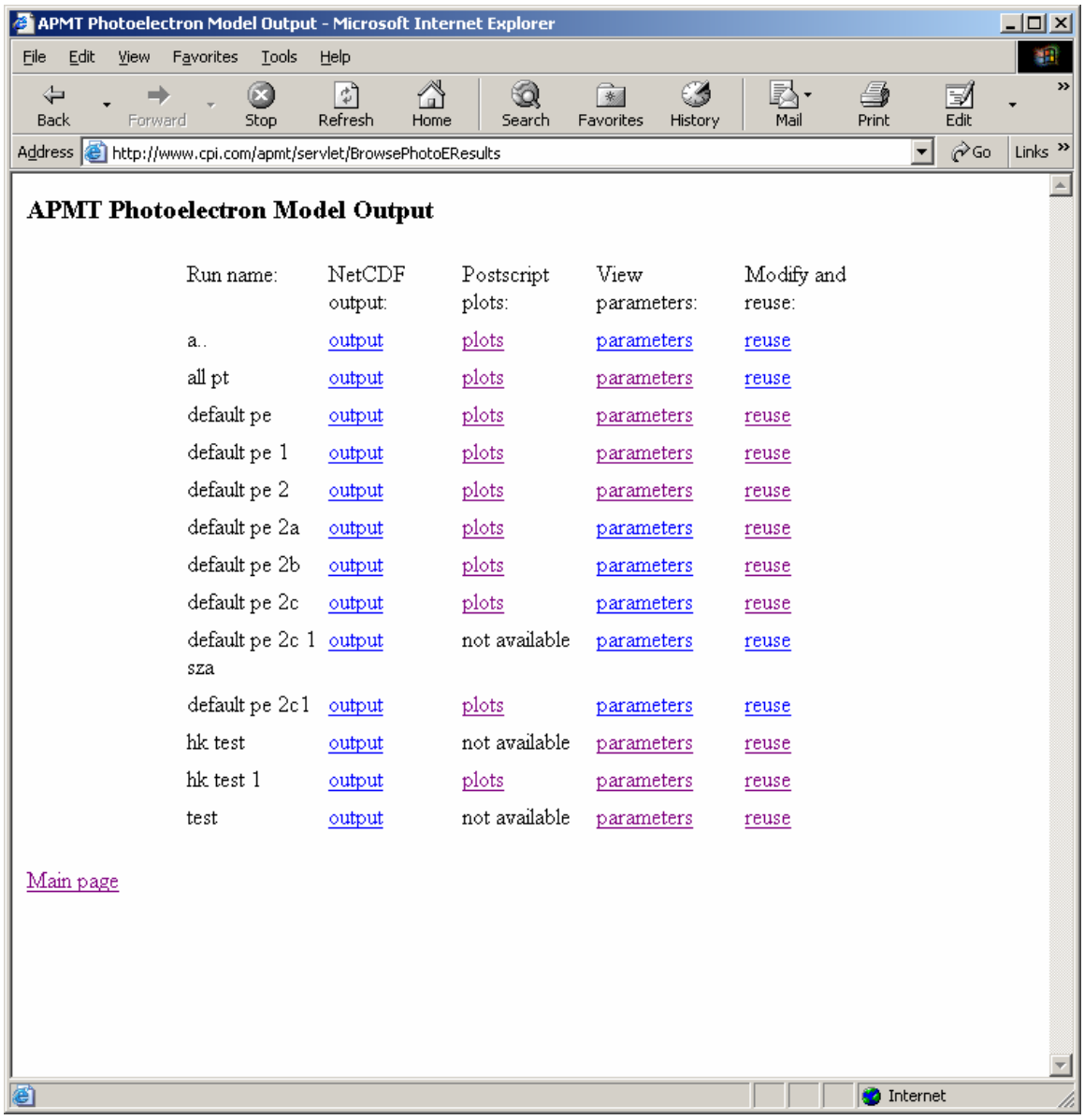



APMT Photoelectron Model Parameters - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Forward Stop Refresh Home Search Favorites History Mail Print Edit
Address http://www.cpi.com/apmt/servlet/PhotoEParamInp?parameters:PE_SPACE_main_SPACE_12
Go Links
ap 6 hrs before current time 6.0
ap 9 hrs before current time 3.0
ap 12 to 33 hrs bef curr time 3.63
ap 36 to 57 hrs bef curr time 13.25
Adjustments to Hinteregger spectrum
Multiplier 1.0
Begin waveband (Å) 1.0
End waveband (Å) 1.0
Molecular band system synthetic spectra options
NO BANDS SYN
N2 1PG SYN
N2 2PG SYN
N2 LBH SYN
N2 BH1 SYN
Resonance line photon transport options
1356 A
1304 A
1040 A
1026 A
989 A
1048 A
1066 A
832 A
833 A
834 A
Wait for run to complete
Compute
Main page
Done
Internet


APMT Auroral Electron Model Parameters - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Forward Stop Refresh Home Search Favorites History Mail Print Edit
Address http://www.cpi.com/apmt/servlet/AuroralParamInp?parameters:AE_SPACE_main_SPACE_15
Go Links
APMT Auroral Electron Model Parameters
Modify the following parameters and then click the compute button to run the model:
(You have to change the run name.)
Run name AE main 15
Geophysical parameters
Year 1992
Day of year 80
Universal time 4500.0
Number of altitude grid points 100
Highest altitude grid point (km) 1000.0
Latitude 59.3
Longitude 0.0
F10 previous day 150.0
F10 81 day average 150.0
Ap daily 10.0
ap current time 3.0
ap 3 hrs before current time 3.0
ap 6 hrs before current time 6.0
ap 9 hrs before current time 3.0
Viewing geometry
Observer altitudes (km) 500.0
Zenith look angles (deg) 180.0 175.0 170.0 165.0 160.0
Spectral parameters
Starting wavelength (Å) 1300.0
Stopping wavelength (Å) 2000.0
Wavelength grid spacing (Å) 1.0
Instrument resolution (Å) 1.0
Rotational temperature (K) 400.0
Vibrational temperature (K) 400.0
Done
Internet


APMT Auroral Electron Model Parameters - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Forward Stop Refresh Home Search Favorites History Mail Print Edit
Address http://www.cpi.com/apmt/servlet/AuroralParamInp?parameters:AE_SPACE_main_SPACE_15
Go Links
ap 3 hrs before current time 3.0
ap 6 hrs before current time 6.0
ap 9 hrs before current time 3.0
ap 12 to 33 hrs bef curr time 3.63
ap 36 to 57 hrs bef curr time 13.25
Incident flux
Characteristic energy (keV) 5.0
Energy flux (erg cm-2 s-1) 10.0
Gaussian
Maxwellian
Incident flux altitude (km) 626.0
Ionosphere (exponential)
Intended for energy loss to plasma in F-region
Electron density (cm-3) at 350 km 20000.0
Ionospheric scale height (km) 150.0
Instrument resolution (Å) 1.0
Rotational temperature (K) 400.0
Vibrational temperature (K) 400.0
Molecular band system synthetic spectra options
N2 1PG SYN
N2 2PG SYN
N2 LBH SYN
N2 BH1 SYN
Resonance line photon transport options
1356 A
1304 A
1026 A
989 A
Wait for run to complete
Compute
Main page
Done
Internet

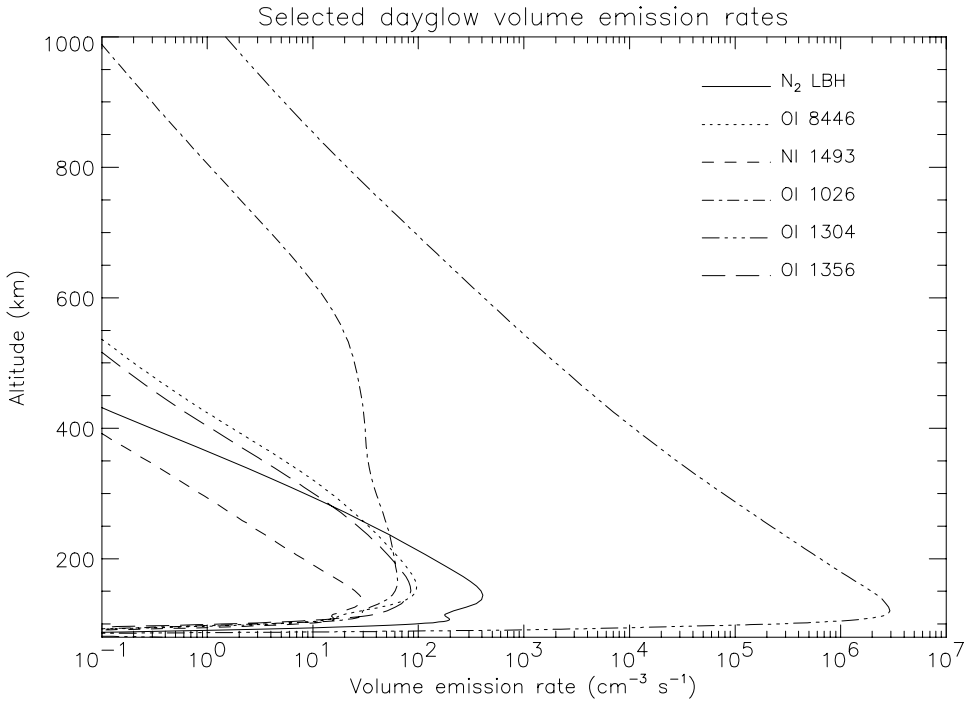
The next screen capture shows how complete runs are listed:

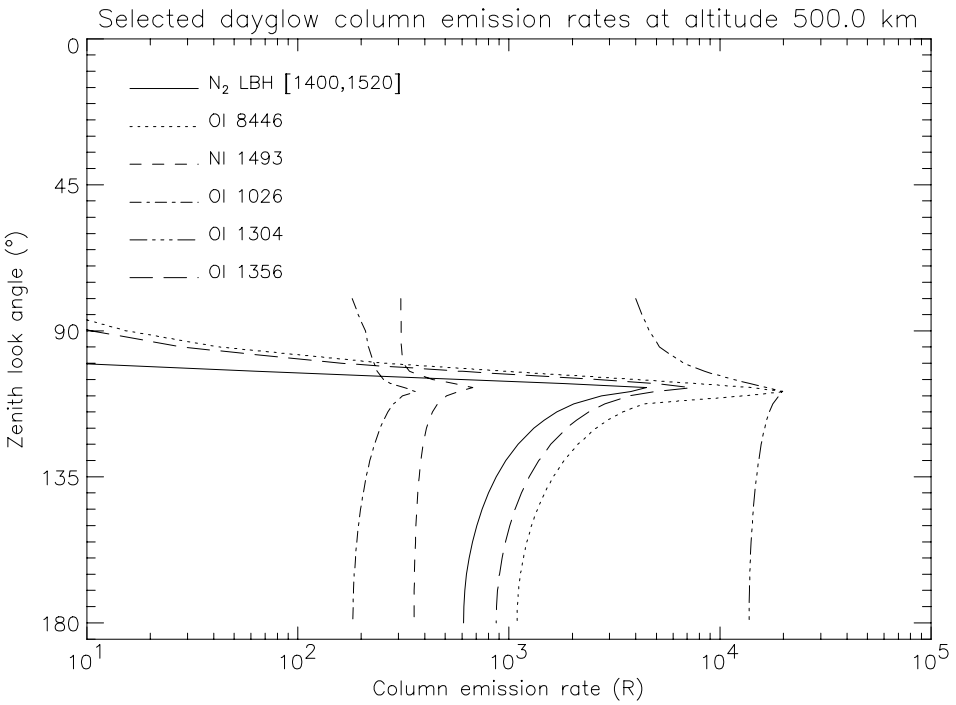


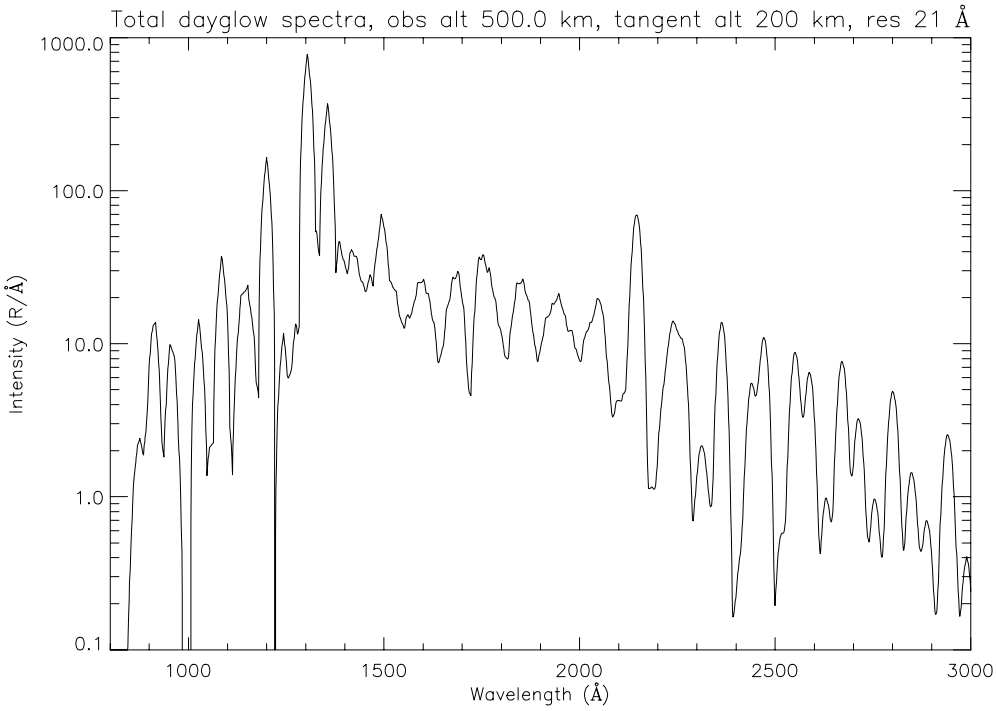
APPENDIX C:
Plots of model output

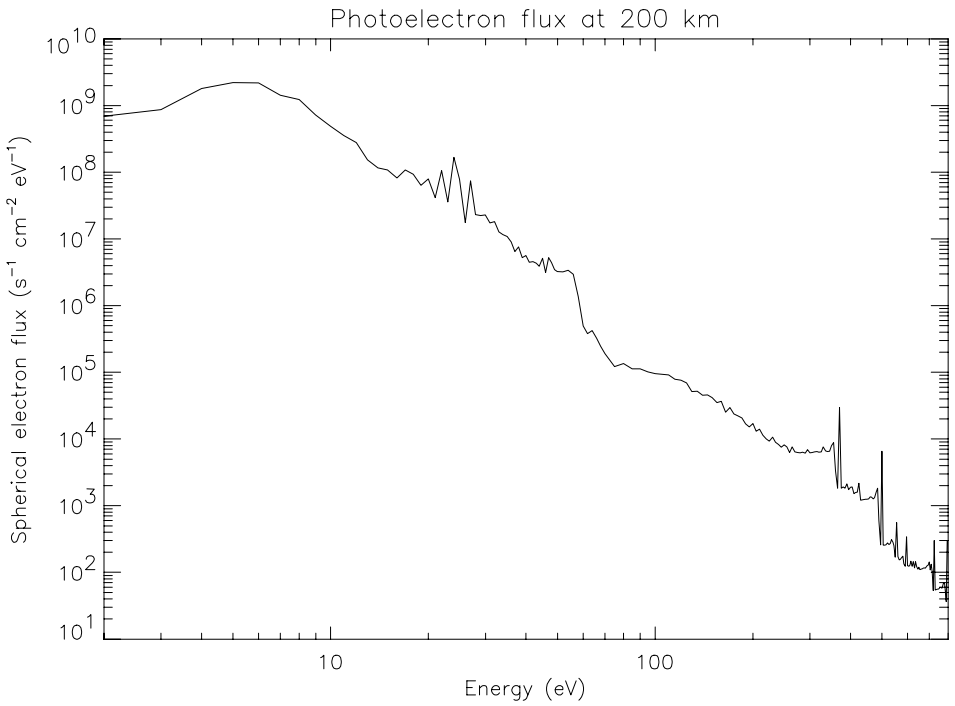
The following plots were generated from APMT output for input parameters similar to those in the screen captures of Appendix B. The plots of volume emission rates, column emission rates, and total spectra are similar to plots that can be obtained from the web interface as described in Appendix A. All of the numerical results displayed in the plots below are consistent with model output from AURIC, B3C, and Redister.

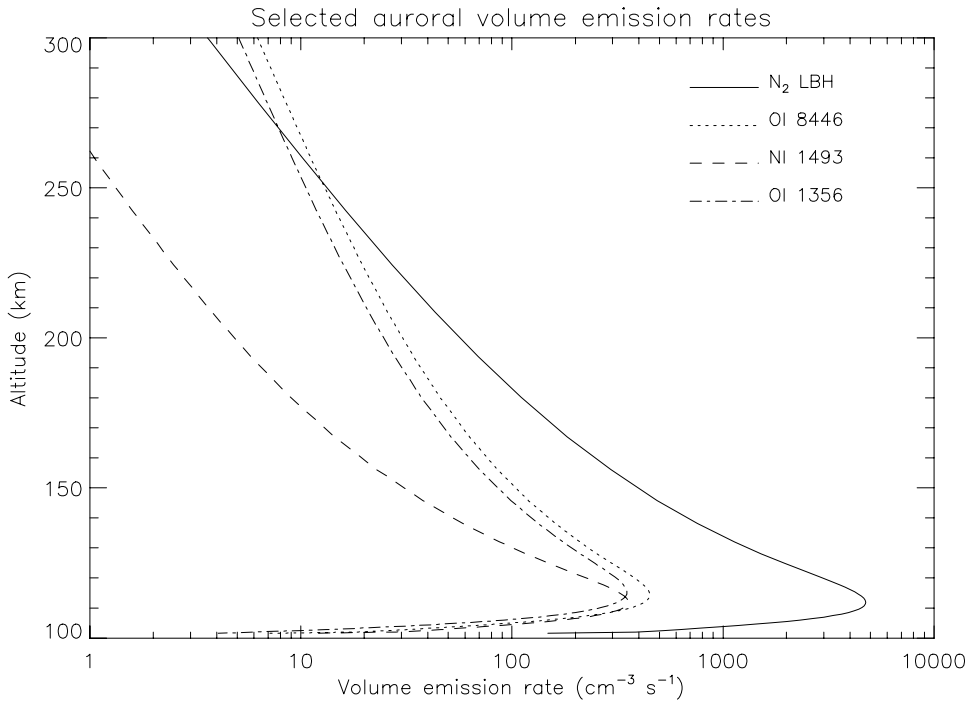
In the plot below OI 1304 has a much higher volume emission rate than the other selected features, while strong self-absorption brings its column emission rate down to a level similar to the other features in the next plot after the one below.

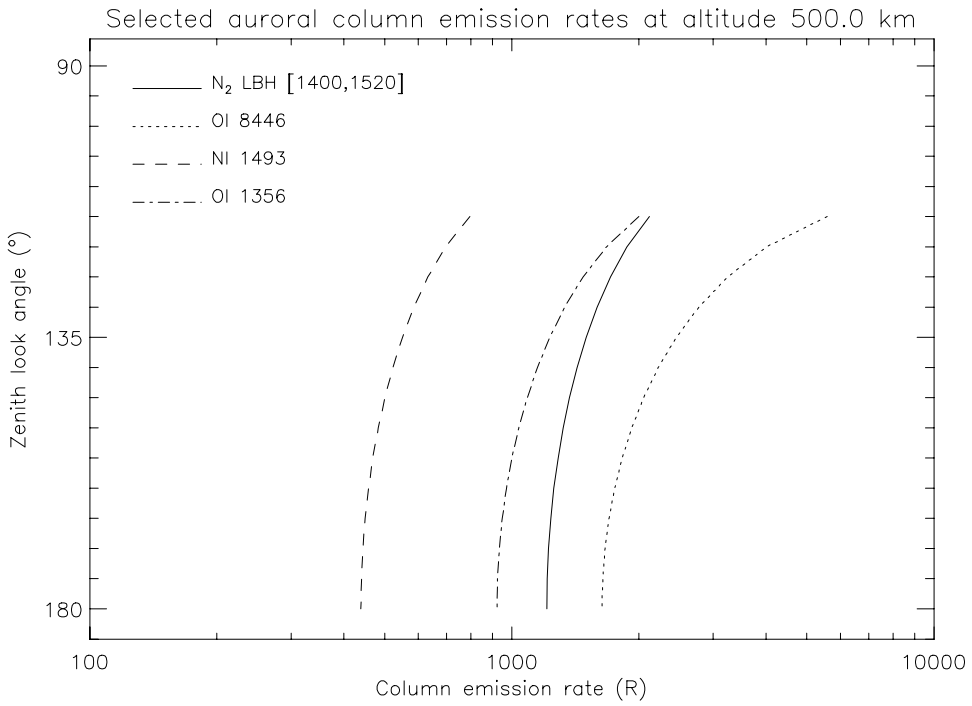



Selected dayglow column emission rates at altitude 500.0 km
N2 LBH [1400,1520]
OI 8446
NI 1493
OI 1026
OI 1304
OI 1356
Zenith look angle (°)
0
45
90
135
180
10^1
10^2
10^3
10^4
10^5
Column emission rate (R)

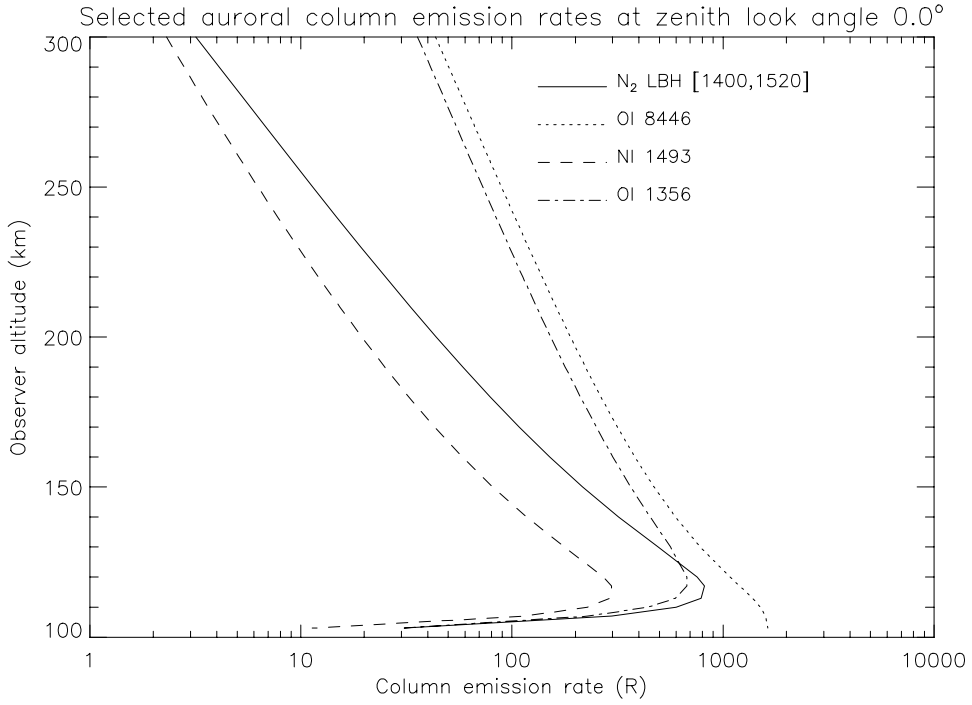

Total dayglow spectra, obs alt 500.0 km, tangent alt 200 km, res 21 Å
Intensity (R/Å)
1000.0
100.0
10.0
1.0
0.1
1000
1500
2000
2500
3000
Wavelength (Å)

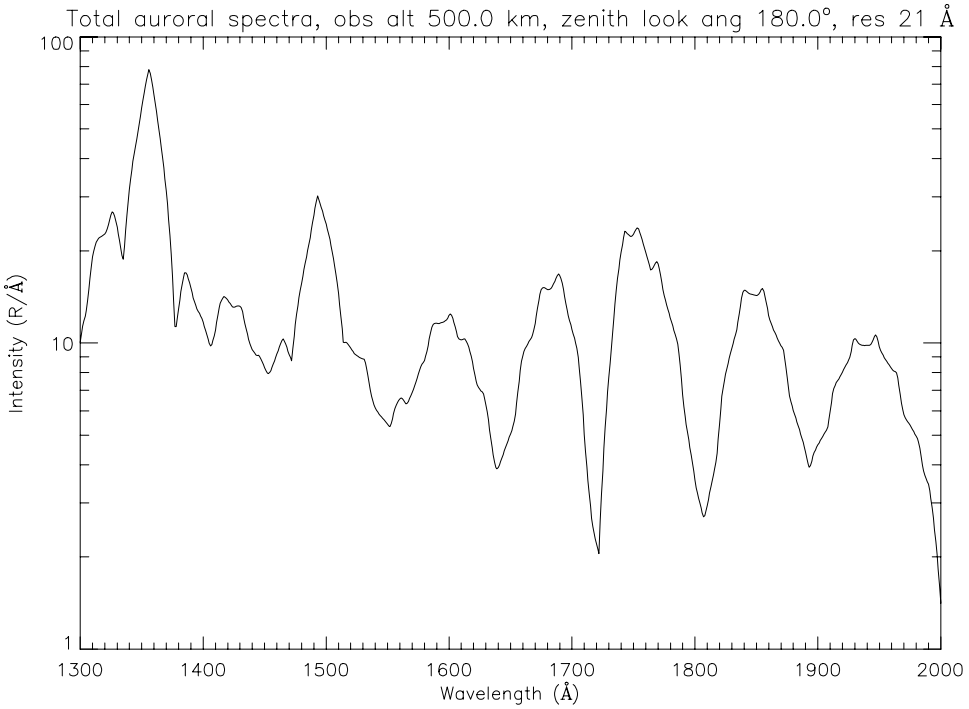

Photoelectron flux at 200 km
Spherical electron flux (s^{-1} cm^{-2} eV^{-1})
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10
100
Energy (eV)

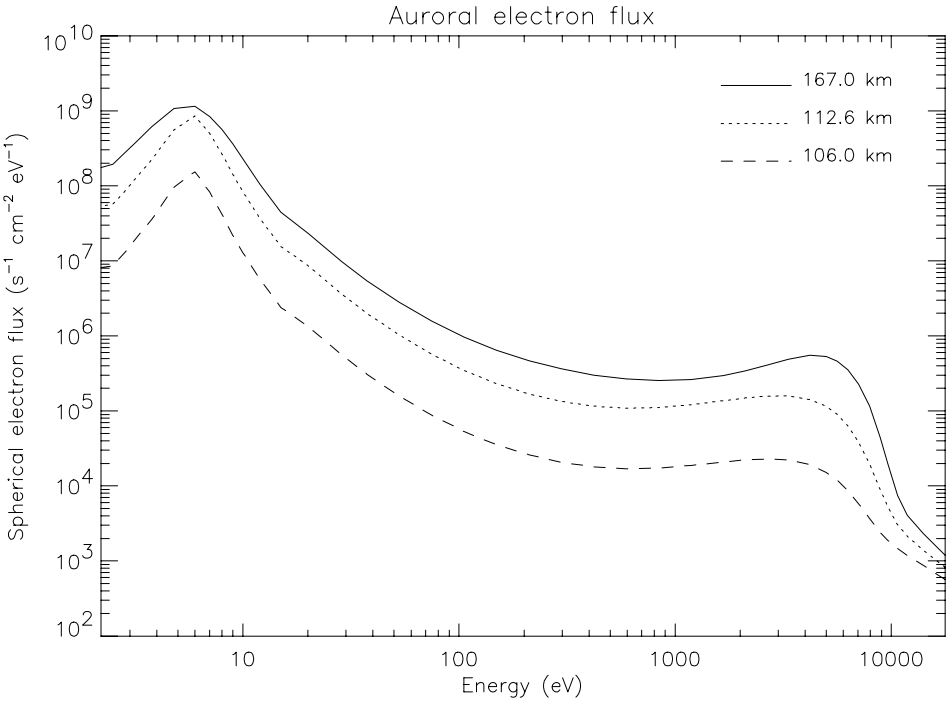

Selected auroral volume emission rates
N_2 LBH
OI 8446
NI 1493
OI 1356
Altitude (km)
300
250
200
150
100
1
10
100
1000
10000
Volume emission rate (cm^{-3} s^{-1})



The following is an example of a rocket mode plot of column emission rates versus observer altitude, which is one of the types of plots that can be obtained from the web interface (see Appendix A).




Total auroral spectra, obs alt 500.0 km, zenith look ang 180.0°, res 21 Å
Intensity (R/Å)
100
10
1
1300
1400
1500
1600
1700
1800
1900
2000
Wavelength (Å)


Auroral electron flux
Spherical electron flux (s^{-1} cm^{-2} eV^{-1})
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
167.0 km
112.6 km
106.0 km
10
100
1000
10000
Energy (eV)